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Proposal to Study High Energy Collisions

in the 30" Hydrogen Bubble Chamber

Warsaw Bubble Chamber Group

Warsaw University and
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August 1971

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The Warsaw Bubble Chamber Group of the Warsaw
University and of the Institute of Nuclear Research would
like to participate in the analysis of the film from the 30"
Hydrogen Bubble Chamber exposed to a high energy beam at the
National Accelerator Laboratory.

The present proposal concerns the problems which can be
solved by measuring and analysing the high energy hadron
interactions recorded on about 50 000 pictures.

Most of the discussion given below is valid for any type of
the incoming hadron. However the proton-proton collisions
have an advantage coming from the symmetry of the initial
system: the one - particle inclusive distributions can be
fully determined by measuring only the particles emitted into
the backward hemisphere in the c.m. system, which have
relatively low laboratory momenta. Also in the investigations
of the exclusive reactions or the many-particle inclusive
correlations the forward-backward symmetry in the c.m. system
can be used as an "a posteriori" check against biases which
might be introduced by the experimental procedure.

An additional argument favouring the study of the pp collisions is connected with the fact that the data from the CERN Intersecting Storage Rings are now becoming available. They allow to observe the energy dependence of the investigated phenomena in the wide energy range. The energy dependence of the cross sections is closely related to the nature of the dominant exchange mechanism, it allows to verify scaling laws etc, and thus is essential in the analysis of the high energy hadron collisions.

It would be therefore highly desirable to have close contacts between laboratories studying the same process at different energies. Such collaboration would require a certain standarization of the experimental procedure and of the form in which the data are collected, but it would facilitate a comparison of the final results at different energies.

It seems that the seperation of different channels at energies of about 100 GeV will not be possible. One may hope to separate only the channels without neutral particles by kinematical fitting with 4 constraints or perhaps more frequently with 3 constraints when the momentum of one charged particle is unmeasurable. The discussion given below remains valid even if the separation turns out to be doubtful.

We intend to apply the ionisation criteria to distinguish slow protons /with $p_{lab} < 1.5$ GeV/c / from π^+ mesons. Moreover, in the case of the p p collisions one can try also to separate fast protons following the statistical method based on the symmetry property, described by D.B.Smith.

In the sample of the 2-prong events there will be an

important contribution of the elastic events. We intend to identify them by. the accurate measurements of the recoil proton /angle plus range or curvature/ and of the direction of the scattered particle. If the corresponding counter measurement is delayed, the determination of the differential elastic cross section will be an important result of the discussed experiment.

The programme of investigations proposed below concerns only the sample of inelastic events. With about 50 000 pictures taken at one energy the studies of the following problems should bring an important information:

1. Prong multiplicity distribution,

2. Determination of number of π^o mesons,

3. Single-particle distributions,

4. Production of resonances,

5. Production of neutral strange-particles,

6. Test of the hypothesis of limiting fragmentation,

7. Verification of the scaling hypothesis,

8. Comparison of the data with predictions of various phenomenological models.

1. Prong multiplicity distribution

Information on prong multiplicity is the easiest to obtain as it requires scanning of the film only. There is a great interest both in the average multiplicity dependence on energy and in the shape of the distribution of the number of events with different prong numbers.

The first problem is important because there is still an uncertainty whether the growth is logarithmic or has a power character. The scaling hypothesis predicts a definite dependence which asymptotically becomes logarithmic, as it is also true for multiperipheral models[1]. At the Amsterdam Conference in July 1971 there were doubts concerning the existence of the drastic change from the steep rise of the multiplicity in the accelerator region to a more gentle growth suggested by the cosmic-ray data of Jones et al[2]. In addition the data from Serpukhov at 70 GeV/c seem to yield a multiplicity which is higher than expected from the Echo-Lake experiment. These problems could be easily solved with a series of accurate points at the Batavia energies.

The problem of the shape of the multiplicity distribution is also currently under discussion. After the evidence against the Poisson distribution and the distributions proposed by C.P.Wang has been found, the distribution which at the moment seems to fit all the existing data is the one with 2 free parameters proposed by Czyżewski and Rybicki /for a review of this problem and related references see the Rapporteur's Talk of A.Wróblewski at the Kiev Conference[3]/. All the present

knowledge should be verified at higher energies where the width of the prong distribution becomes larger and tests will be more conclusive.

The energy dependence $\overset{and}{}$ the shape of the prong multiplicities for energies below 30 GeV show a striking regularity[4] which, in order to be confirmed or disproved, needs good data on high multiplicities /8-16 prongs/ attainable at the Batavia energies.

2. Determination of number of π^{o} mesons

A hydrogen bubble chamber is not a very efficient detector of the gamma rays, nevertheless it may be used to determine the average number of produced π^{o} mesons per interaction for separate multiplicities and for the total sample of inelastic events.

At 100 GeV one may expect about $3\pi^{o}$ mesons, i.e. 6 gamma rays, per event. The average detection length in the 30" chamber will be about 40 cm, which is equal to 4% of the radiation length. Therefore one may expect $3x2x0.04 = 0.24$ gamma rays per event and hence about 2400 recorded gamma rays for 10 000 events.

In a hydrogen bubble chamber it is easy to verify which of the recorded electron pairs are pointing to the interaction vertex; the measurement of the potential and actual path length allows then to determine the detection efficiency and the average number of π^{o} mesons.

It will be possible to find the dependence of the average

number of π^o's on multiplicity which was shown[5] to be a severe test of the models of high energy interactions.

3. Single-particle distributions

One of the simplest and relatively easiest things to be done in the proposed experiment is a study of single-particle distributions.

As already discussed in the introduction the identification of positive particles will be possible up to the momentum of about 1.5 GeV/c. All negative particles may be assumed to be pions. In addition, for the proton-proton collisions the distributions of the backward and forward particles in the c.m. system must be identical. Therefore a complete knowledge of the π^- distributions will be easily achieved and the positive particles identified by their ionisation may be used to identify the particles with higher laboratory momenta[6].

The single-particle distributions may be studied for separate multiplicities and for the sum of all channels. The latter ones are especially interesting and their importance for testing the presently discussed hypotheses will be discussed separately in sections 6 and 7.

The distributions for separate multiplicities will allow to study the dependence of the longitudinal and transverse momenta on multiplicity and energy. It will be interesting to study the dependence of the average transverse momenta on number of prongs which at highest energies seems to become flat[7].

We would also like to study single-particle distributions in different variables like the c.m. momentum, transverse and longitudinal momenta, rapidity etc, and to parametrise them in terms of different pairs of those variables. We would like to verify whether the dependence of the average transverse momentum on the longitudinal momentum for pions shows the "sea-gull effect" observed at lower energies. It seems interesting to search for a pair of variables in which the particle distributions are as simple as possible and may factorize.

4. Production of resonances

For all particles for which the momentum determination will be feasible one may study various mass distributions to detect resonance production. It will be possible to determine the effective masses of systems composed of identified protons, identified π^+ mesons and measurable negative pions, and to study production of isobars which are slow in the laboratory system.

One of the interesting problems to be answered is the relative ratio of the $\Delta\ (I = 3/2)$ production to the $N^*\ (I = 1/2)$ production. It will bring an information about the importance of the Pomeron exchange and its expected dominance over all the other exchanges for higher and higher energies.

One may also search for mesonic resonances and heavy isobars.

In the case of the pion-proton collisions at the incident energies of about 100 GeV an accurate determination of the effective mass of the forward mesonic systems will be

impossible, but a study of the systems composed of the nucleon and pions will be as easy as in the case of the proton-proton collisions and will bring an information about the nucleon excitation.

5. Production of neutral stange particles

The production of neutral strange particles can be studied in inclusive reactions $pp \rightarrow \Lambda^o$ + anything and $pp \rightarrow K^o$ + anything.

The total cross section for strange particle production in pp collisions increases from /2.05 $\pm$ 0.14/ mb at 10 GeV/c[8] to /4.20 $\pm$ 0.45/ mb at 24.5 GeV/c[9]. Assuming the cross sections for Λ^o and K^o production to be equal to those determined at 24.5 GeV/c[9] one expects the production in the backward hemisphere of 100 Λ^o hyperons decaying into $p\pi^-$ and of 120 K_1^o mesons decaying into $\pi^+\pi^-$ per 10 000 beam interactions. However, part of the decays takes place outside the chamber. The lab. momenta calculated for $p_L = 0$ and $p_T = 0.5$ GeV/c, are 8.9 GeV/c for Λ^o and 5.1 GeV/c for K^o produced in 100 GeV/c pp collision; they correspond to mean decay lengths of 60 cm and 25 cm, respectively. Thus in the 30" chamber the escape probability should not exceed 50% even for the fastest particles in the lab. system, if only the backward c.m. hemisphere is considered.

In the case of the incident π^- beam the estimated number of $K_1^o \rightarrow \pi^+\pi^-$ decays is 480 and the number of $\Lambda^o \rightarrow p\pi^-$ decays is 200 per 10 000 interactions. These numbers were

obtained using the cross sections measured by the Wisconsin
group[10/] at 25 GeV/c. In the incident energy region up to
25 GeV most of the Λ^0 hyperons are emitted backwards in the
c.m. system[10/] and one may expect that they will be
measurable in the 30" chamber at 100 GeV, but a large fraction
of K_1^0 mesons will probably escape detection.

The study of neutral strange particle production is
easier in the case of pp interactions and it can yield the
following information:

1/ the total cross-sections for Λ^0 and K_1^0 production,

2/ the momentum spectra of Λ^0 and K^0 produced in the
inclusive process $pp \rightarrow \Lambda^0$ /or K^0 / + anything. The systems
$pp\bar{\Lambda}$, ppK^0 and $pp\bar{K}^0$ are exotic and therefore the differential
cross-sections for Λ^0 and K production should reach the
asymptotic form already at low energies.

6. Test of the Hypothesis of Limiting Fragmentation

The high energies of the Batavia accelerator make
possible a test of the Hypothesis of Limiting Fragmentation[11/]
and the recent prediction of Chan et al[12/] about the way in
which this asymptotic situation is reached. In the case of
the proton-proton collisions the test may be performed in the
laboratory system where for the low momentum particles /which
are the fragments of the target proton/ one can identify
protons, π^+ and π^- mesons. The high energy limit for both
π^+ and π^- distributions should be reached at low energy
/the state $pp\pi^{\pm}$ is exotic/ whereas for secondary protons the

convergence is expected to be much slower /the state ppp
is not exotic/.

One may identify protons and π^+ mesons up to about
1200 MeV/c in the laboratory system and then determine the
double differential cross section $d^2\sigma /dp_L^{lab} dp_T$, and its
projections, like e.g. the distribution of the laboratory
longitudinal momentum p_L^{lab} . A study of such distribution
as function of energy from the present accelerator data up
to the highest Batavia energies would be a crucial test of
the HLF.

7. Test of the scaling hypothesis for pions in the c.m. system

The scaling hypothesis suggested by Feynman[13] should
apply to the single-particle distributions of the produced
pions. It predicts the energy independence of the invariant
cross section $E \ d^3\sigma /d_3p$, when expressed in terms of the
variable x (equal to the c.m. longitudinal momentum p_L over
the initial proton momentum p_0) and p_T, the transverse momentum.

This hypothesis in the region of low laboratory momenta
has been shown to be equivalent to the Hypothesis of Limiting
Fragmentation. However for $x \approx 0$ /for slow particles in the
c.m. system/, where H.L.F. has no definite prediction, scaling
predicts a specific rise of the $d\sigma /dx$ distribution which
should develop an infinite peak. This peak produces in turn
a logarithmic growth of the multiplicity discussed above.

The best particles to test this $x \approx 0$ region are the
negative pions which can be identified and measured /fraction

of K^- mesons is expected to be small/. At 100 GeV of the incident proton energy a pion with $p^{cm} = 0$ and $p_T = 300$ MeV/c will have laboratory momentum of about 2.4 GeV/c, and the corresponding value for 200 GeV incoming protons is 3.4 GeV/c. The c.m. momentum distribution of negative pions emitted in the backward hemisphere can be therefore accurately reconstructed and compared with the data for lower energies /like those of Smith et al[6] or of the Scandinavian Collaboration[14]. It will be possible to verify whether the tendency of the peak at $x = 0$ to grow faster than predicted from scaling, as it is observed in the 13 to 30 GeV energy region and in the Echo Lake experiment[2], will be confirmed.

In the case of the incoming particle other than proton the colliding system is no more symmetric. It is then desirable to test the hypothesis of scaling for both backward and forward c.m. hemisphere, at least in the region of $x < 0.3$. The accurate measurements for this region will be again possible for the incoming particle with momentum of 100 GeV/c, but for 200 GeV/c the forward part will be well measured only up to $\bar{x} = 0.15$. For still more forward particles one may check scaling using the existing low-energy data on the cross section $E \, d^3\sigma / d_3 p$ and comparing the measured laboratory angular distribution with the one predicted from scaling. For interactions of negative pions one may use for comparison e.g. the Notre Dame data at 8 and 18.5 GeV/c or the Aachen-Berlin-Bonn-CERN-Cracow-Heidelberg-Warsaw data at 16 GeV/c.

8. Comparison of the data with predictions of various phenomenological models

In a final stage the data from the discussed experiment should be useful for testing various phenomenological models.

We expect that in one-year time there will appear new versions of the multiperipheral model based on the experience with the previous versions, like the multi-Reggeon-exchange or multi-pion-exchange models. There should be a progress in the development of the Veneziano model to the many-body reactions. The very high energy data from Batavia will provide valuable tests of such models and will allow to fit more precisely free parameters and to discriminate against too many arbitrary assumptions appearing in the analyses performed by now.

The new way of data presentation in terms of the longitudinal phase space[14/] should become more and more appropriate with increasing energy. By now this method has been applied only to the fitted channels but there is no basic argument against its applications to the unseparated data. At present the longitudinal phase space method is applied mainly in low multiplicity reactions as a phenomenological method of data analysis but it starts to be developed to reactions of higher multiplicity[15/] and to become more quantitative.

For the π p collisions one of the most interesting recent findings was the observation of the Wisconsin group

that the pion production is symmetric not in the c.m.
system but in the frame where the quarks from the initial
pion and proton have the same momenta. This would suggest
a qualitative quark-quark model of high energy collisions,
the model which needs further studies possibly at different
energies.

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